Effect of number of layers on the compression behaviour of graphenes

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Graphene has received a lot of attention nowadays due to the fact that as a single, virtually defect-free crystal is predicted to have an intrinsic tensile strength higher than any other known material[1]. Regarding tension, the original experiments employed bending of suspended flakes on an AFM apparatus have yielded, with the help of adequate modelling and a number of assumptions, values of tensile strength of 130 GPa. So far however, these values have not been confirmed by direct uniaxial or biaxial experiments. In compression, however, it is clear that thin monoatomic membranes have no practical resistance to compression. This picture however changes dramatically when graphenes are embedded in polymer matrices such as PMMA. As shown in our recent publications[2,3] exfoliated monolayer graphene exhibits a compression strain to first failure (Euler buckling) of 0.6% which is indeed a very high value for its overall dimensions (typically 30 by 20 μm). Furthermore, the obtained values are not affected by the flake size and can be modelled quite adequately by considering Winkler-type of mechanics upon loading[2,3].

In this work, graphene flakes with thickness of 1 to 3 layers were tested under axial compression on a four-point-bend rig. In figure 1a-c selected results from the compression experiments are presented. By monitoring the position of the 2D Raman peak versus applied strain we can estimate the point of elastic (buckling) or yield (cohesive) failure of the various specimens. Moreover, the slope of the Raman frequency vs. strain is indicative of the stress transfer efficiency of the system. Initially as expected phonon hardening at a slope of -56 $cm^{-1/\%}$ is observed. As the compressive strain increases, a plateau is reached which corresponds to the failure of the graphene while further loading causes phonon softening. As mentioned above, the monolayer graphenes failed at a critical strain of -0.6% with Euler-type of elastic buckling of failure[1]. However, as the number of layers increases the critical strain to failure was found to decrease. Since the thickness of the graphene specimens increases with number of layers one would expect for an elastic instability the inflection point is shifted to higher strains. The fact that a notable decrease of the plateau strain (inflection point) is observed indicates that the mode of failure is different than that observed for a monolayer. In particular, the bilayer graphene failed at a strain of -0.25% and the trilayer at a strain of -0.20%. This behaviour can be attributed to the weak interlayer bonding between the individual graphene layers. In fact the bonding between the graphene outer surfaces and the polymer matrix is estimated to be higher than that of the internal graphene-graphene bonding and cohesive failure is promoted prior to Euler buckling. We conclude therefore that in multilayer graphene a lower threshold of critical buckling strain is obtained due to the cohesive failure within the material. The results of the present study provide crucial insight for the effective design of graphene nanocomposites under compression and show that monolayer graphene offers higher resistance to compressive failure than two or three layered graphene materials.

References

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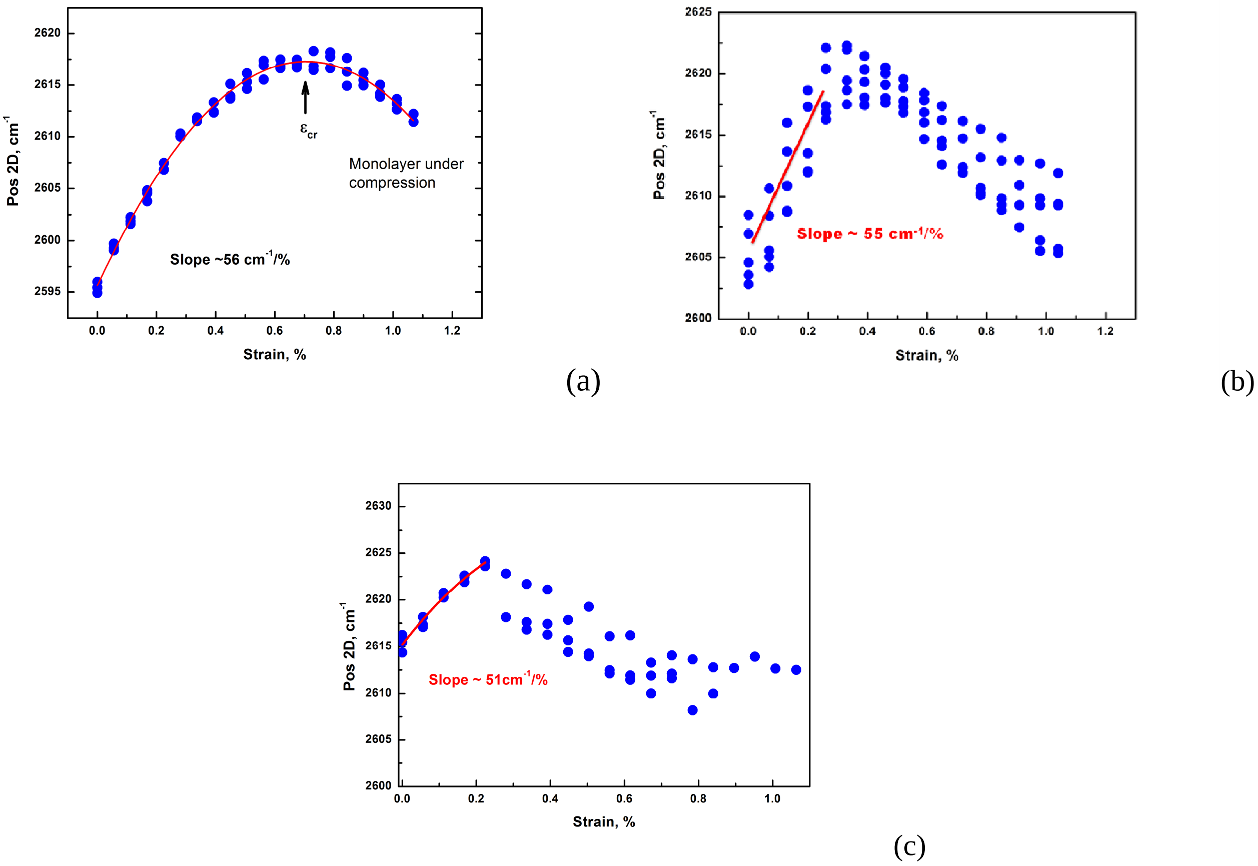

Figure 1: Position of the 2D Raman peak versus the applied strain for (a) monolayer, (b) bilayer and (c) trilayer graphene respectively.